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RESEARCH ARTICLE

4D visualization to bridge the knowing-doing gap in megaprojects: an Australian case study

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Abstract

The literature on megaprojects are oriented towards 'knowing' the problems and 'knowing' the solutions, and there is a dearth in literature aimed at explaining strategies adopted in 'doing' or implementing that knowledge. Particularly, the literature highlights communication as important as part of the 'knowing,' while there is a gap in 'doing,' as performance improvements are still not evident. This research aims to explore how this knowing-doing gap in the communication of risk information was addressed by using 4D visualization. This article discusses the vent facility of a megaproject in Australia as a case study to illustrate the innovation. The 4D model developed for the facility helped the project team to visualize the construction of a critical part of the project, discuss the construction methodology, identify the risks in the construction process and persuade the non-technical decision-makers of the project to take appropriate action. The risks identified through the visualization covered safety, program, and interface risks. This study offers insights into the role of visualization in bridging the knowing-doing gap in the construction industry in the context of a megaproject.

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Keywords:

Megaprojects, knowing-doing gap, 4D visualization, risk management.

Introduction

Megaprojects are projects that are colossal, captivating, costly, controversial, complex, and laden with control issues (Frick, 2008). Due to these characteristics, megaprojects are a different breed compared to normal projects (Capka, 2004). When these projects fail to deliver on their stated objectives, they often fail big resulting in mega-failures. Megaprojects struggle to meet initial performance targets (Gil & Pinto, 2018) such as cost schedules, time schedules, promised benefits, risk mitigation, etc. We call these failures mega-failures because megaprojects cost a lot of money and consume enormous amounts of resources and attention (Söderlund, Sankaran and Biesenthal, 2017) making their inefficiencies prominent and severe. Even though not all failures are big nor have a big impact on project outcomes, because of the controversial nature (Frick, 2008), aided with the media interest, public attention and political interest (Van Marrewijk et al., 2008), even small failures or set-backs affects the perception of all stakeholders involved in the project. Thus, there is a need for research on improving the performance of megaprojects.

Multiple studies stress strategic misrepresentation, optimism bias, stakeholder fragmentation, governance challenges, among others, as causes of failure in megaprojects (Flyvbjerg, 2008; Ninan, Mahalingan and Clegg, 2019; Locatelli & Mancini, 2010; Miller & Hobbs, 2005). Other studies that highlight that these causes of failures can be addressed through appropriate checks, reference class forecasting, governance mechanisms, external interfacing structures (Flyvbjerg, Holm and Buhl, 2002; Flyvbjerg, 2008; Klakegg, Williams and Shiferaw, 2016; Van Fenema, Rietjens and Van Baalen, 2016). Irrespective of this knowledge, megaprojects underperform signifying a gap between 'knowing' the causes of failure along with their mitigation measures and 'doing' what is needed to address these issues. This gap is called the knowing-doing gap (Pfeffer & Sutton, 1999). There is a need to bridge this knowing-doing gap as it is instrumental for improving the performance of the project.

To improve the transfer of knowledge in these projects and improve performance, Davies, Gann and Douglas (2019) advocate a need to build client and contractors capabilities through innovations. Innovation is adapting, integrating, and reconfiguring organizational skills, resources and functional competencies to match the requirements of the changing environment (Teece, Pisano and Shuen, 1997). This article using the case study of an Australian megaproject presents an innovative approach to bridge the knowing-doing gap in the communication of risk information using a 4D visualization approach.

The paper is structured as follows: In the literature review, the current knowledge on risk management in megaprojects and the potential role of visualization in mitigating the risks is summarized before arriving at a set of research questions. Then the methodology used to collect data from a megaproject in Australia and how an innovative 4D CAD model was used to address the knowing-doing gap in the communication of risk information and thereby manage risks successfully is described. The conclusion section then consolidates the findings and outlines the future direction for research in this area.

Knowing-doing gap in the communication of risk information

In this section, we first review the literature on knowing-doing gap in megaproject, following which we highlight communication of risk information, the need for visualization, and review the literature on visualization to arrive at the research gap.

KNOWING-DOING GAP

Cox (2012) describes the omissive behavior of not taking the necessary actions despite the knowledge being available as the knowing-doing gap. Despite an increasing volume of works, megaprojects still seem to underperform. Denicol, Davies and Krystallis (2020) in their review of megaproject literature maps 54 different cures corresponding to 18 causes of poor performance. The poor performance of these projects after the presence of the cures within the literature shows the gap between knowing and doing. This claim is supported by Love and Ahiaga-Dagbui (2018) as they note that despite considerable inroads to understanding poor performance, the mitigation strategies developed have fallen short of their intended goal. The first step towards addressing the knowing-doing gap is to acknowledge that the gap exists (Knight et al., 2008). While majority of research in megaprojects are oriented towards 'knowing' the problems and 'knowing' the solutions, there is a dearth in literature aimed at explaining strategies adopted in 'doing' or implementing that knowledge. The knowing-doing gap also called as the research-implementation gap (Knight et al., 2008) is prevalent in many diverse fields such as organizational science (Starbuck, 2006), ecosystem management (McNie, 2007), information security (Cox, 2012), biological science (Esler et al., 2010), etc.

COMMUNICATION OF RISK INFORMATION

Megaprojects, due to their sheer size, exhibit more unexpected risks that are difficult to identify. Mok, Shen and Yang (2015) highlight that the limited cognition due to the scale of megaprojects results in the inability of the project team to identify all the stakeholders. Once identified, each stakeholder must be convinced of the parameters of the project such as the work environment, the schedule, and the criticality of an activity. The communication of risk information has been identified as important for decision making in projects (De Bruijn & Leijten, 2007; Khanyile, Musonda and Agumba, 2019). Adding to this, Dyer (2017) notes that communication helps establish shared vision of the project's uncertainties and expectations for success. Even though there is 'knowing' as in, the literature highlights communication as important still, there is a gap in 'doing' as performance improvements are not evident. We argue that innovations in visualization of information can significantly improve risk management practices in megaprojects by making the risks easier to communicate with all stakeholders. Within the Australian building industry, Atazadeh et al. (2017) note that 3D models enhanced visual communication and helped overcome communication challenges.

VISUALIZATION FOR RISK MANAGEMENT

Visualization exists in the form of 2D drawings, which represent the construction layout and design and as 3D images which helps to represent various construction components spatially. Building Information Modelling (BIM) is an advanced form of 3D visualization which also embeds information on various components used in construction such as material properties and cost estimates (Aibinu & Venkatesh, 2014). 4D BIM adds the construction schedule to the 3D BIM (Charef, Alaka and Emmitt, 2018) and thus helps in identifying scheduling clashes between different activities in the project and is thus useful in visually comparing the constructability of work methods. BIM use has also been accepted in the construction industry for quantity surveying, project planning, facilities management, sustainability and technology-related risk management (Musa et al., 2016). The improved transparency from the use of BIM reduces the risk of information asymmetry which is common in the construction industry (Forsythe, Sankaran and Biesenthal, 2015). Information asymmetry can enable the contractor to opportunistically take advantage of the client due to superiority of information. Pesek et al. (2019) highlight information asymmetry as a practice that construction industry professionals are aware of and still not addressed signifying a knowing-doing gap. Adding to this, megaproject leadership such as the Managing Director (MD) or Chief Executive Officer (CEO) of the project, rarely comes from a construction background as most of these megaprojects are government-owned and often have a bureaucrat at its helm. The current project management practices such as Gantt charts and 2D drawings do not allow these non-technical stakeholders to completely visualize the extent, location, and implication of the risks (Hartmann et al., 2012). While the language of the engineer is 2D drawings (Ramalingam & Mahalingam, 2018), a similar language cannot be comprehended by the non-technical senior management. This paper explores how visual representation of construction components and construction schedule in the 4D visualization models can improve the communication of risk information and thus help in identifying and reducing organizational risks. The use of 3D and 4D visualization is often criticized for its limited use only for reviewing facility designs and analyzing construction sequences (Hartmann, Gao and Fischer, 2008) and additional usages are not explored. From a sociomateriality perspective, Ninan et al. (2020) argues that ICT in construction can be used for different purposes by different stakeholders in the project.

Even though 4D models are not unusual in megaproject management, this article seeks to understand the role of this innovative visualization technology in addressing the knowing-doing gap and improving the performance of these projects. In particular, this research asks, (1) How does visualization of information help in better management of risks in megaprojects? and (2) How does visualization of information help in convincing the real situation to non-technical stakeholders in megaprojects?

Research methodology

A qualitative research methodology is adopted to understand the role of visualization in a megaproject. A case study methodology is apt for an exploratory study to gain familiarity in a new area (Eisenhardt, 1989). The case study was conducted using an autoethnographic approach by the primary author, who was working in the case project. Most of the decisions in organizations are taken in closed-door meetings due to confidentiality concerns and researchers have fairly limited access to the inner workings of boardrooms (Leblanc & Schwartz, 2007). Autoethnography, wherein the researcher is already an employee who has access to these inside experiences, can address the limitations of other research methods (Adams & Manning, 2015). A researcher who is part of the project has access to these meetings and can guard the confidentiality of the project by disclosing only data relevant to the topic under investigation, the role of 4D visualization for bridging the knowing-doing gap, in this instance.

Autoethnography draws meaning from the interactions between the researcher and the culture (Zubriski et al., 2019). It is a form of self-narrative that places the self within a social context (Reed-Danahay, 1997). Anderson (2006) records that autoethnography research needs to meet criteria such as the researcher being a full member of the research setting, being an author of the publication, engaging in analytical reflexivity and dialoguing with other informants. In this research, the primary author was a member of the project controls team in the case selected, talked to others in the project daily, and documented these in the daily reflexive journal (Koch & Harrington, 1998). The data collected includes journal entries and notes from the primary author's experience in the project over six months from August 2017 to January 2018. The approach used in this study is a participatory approach that has been previously applied in the construction industry to collect data through observation and interaction with participants to establish theories (Ma et al., 2018; Hamid & Tutt, 2019)

The case selected to understand the role of visualization in risk management was a motorway infrastructure transportation megaproject in Australia. The planned cost of the project was 16.8 billion AUD (13.18 billion USD). The project aimed to connect the western part of a major city which housed the majority of the population and the eastern part of the city, which has all the jobs. More than two-thirds of the project is being built underground to ease surface road congestions and improve productivity and efficiencies for all road users, including buses, freight, and light commercial vehicles. This research uses a detailed study on the construction of a part of the megaproject – a road vent facility which is planned to finish in eleven months with nine months for construction and two months for inspection and commissioning. This underground construction makes the project more complex than conventional projects along with being costly, colossal and captivating, thus supporting the qualitative categorization of the project as a megaproject (Frick, 2008). The height of the vent facility is 74 m (48 m underground and 26 m above ground) which is comparable to a 25-story residential tower with 3 m floor intervals. The construction of the vent facility was selected to illustrate the use of an innovative approach to assess several scheduling challenges and risks that existed with the delivery of this facility. Thus, this case can be considered as a critical case (Flyvbjerg, 2006a) as it used an innovative approach to address the knowing-doing gap and therefore matched with this research's agenda.

The overall BIM adoption is low in Australia (Aibinu & Venkatesh, 2014). This project too did not use a BIM system and hence a 4D model was created from the information available. The design and structural information for the facility were available in 2D CAD as per the norm. However, a 3D model was required for preparing a 4D schedule. The 3D model as per BIM needs is to be made up of elements that have information in construction such as columns, beams, floors, walls, etc., and simple conversion of a 2D CAD to 3D CAD will only be a collection of points, lines, and faces which convey no meaning. In the case considered, where 2D drawings are the norm, preparing the 3D model at this stage from scratch would require a substantial effort. Instead, the project team used the 2D CAD information available with some 3D rendering to create the 3D models of buildings and site works. There are off-the-shelf software packages available that can combine a schedule (prepared from a scheduling package) with a 3D CAD model (prepared using a standard CAD package) and link them together. The vent facility project used a 4D scheduling package to link a Primavera schedule to the 3D CAD model thereby creating the 4D schedule. The software package used was Synchro Pro. The 4D model generated was very detailed with the minimum units of durations being 'days' and various working calendars and shifts were identified and incorporated.

It was important for the 4D CAD model and subsequent review to be an independent assessment, and hence a consultant was appointed by the client-agency to carry out the visualization model. Independence was necessary for creating the model as the contractor's schedule update and the forecast was being challenged, and an independent view was necessary to show that the report was not biased. The client organization along with the consultants created the 4D CAD model, then conducted briefing sessions for the project personnel along with risk workshops for the site team. As in the real structure, the model components were arranged into substructures, and these were subsequently constructed and assembled into structures of increasing complexity. Additional modeling software was then applied to manage the model components, their arrangement, and their sequence in a construction context, giving the visualization a fourth dimension: time. Figure 1 shows a screenshot of the 4D CAD model created.

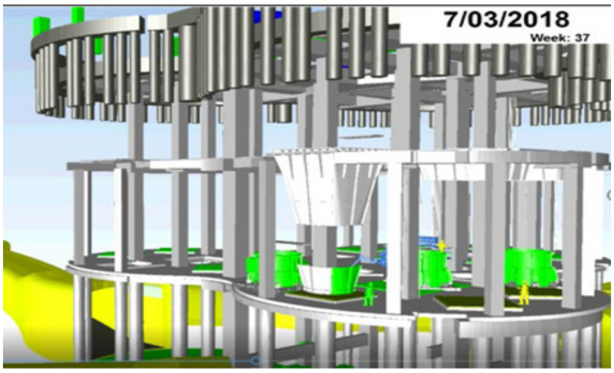

Figure 1 4D model created in the case study project

The constructability reviews were conducted to understand the construction process and construction challenges. The 4D CAD visualization model enabled a deeper understanding of the construction process and was instrumental in convincing the non-technical stakeholders involved with the project. As highlighted in Figure 2, it also improved the understanding of construction challenges, in the form of program risk, safety risk and interface risk, and thereby enabled better risk management.

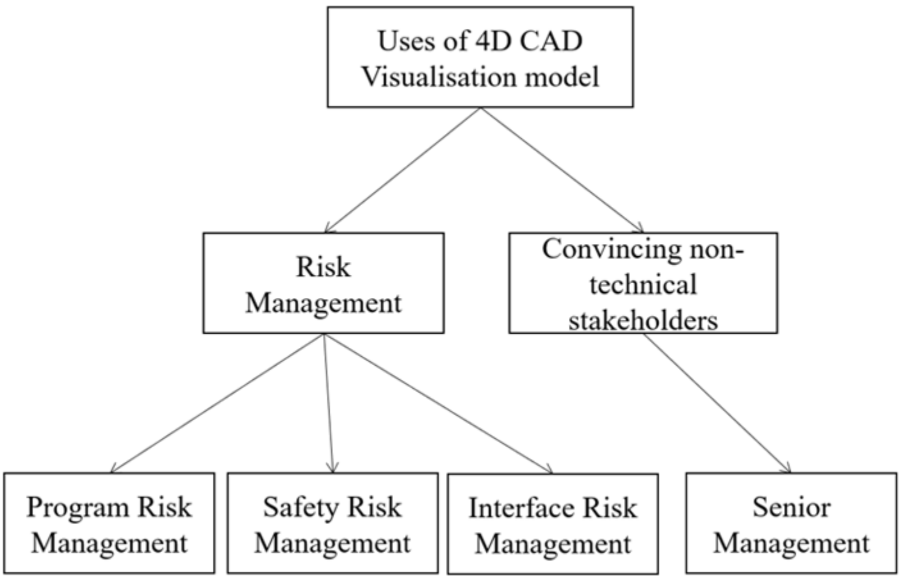

Figure 2 Uses of 4D CAD Visualization from the case study

A 4D visualization and planning exercise was used to have a better understanding of the schedule, deliverables and stakeholder management. This visualization process helped the project to integrate the schedule with the drawings and model, and to highlight the areas of concern which are potential risks and may delay the construction of the facility.

Risk management in the Australian case

Using the 4D CAD model potential risks were identified, and appropriate risk management was carried out to mitigate the risks. The risk management carried out in the project was categorized into safety risk management, program risk management, and interface risk management as shown in Table 1. Each of these is discussed in detail.

Table 1 Risks and mitigation measures observed from the case

Sl. No	Risks	Mitigation Measures
Program Risks		
1	More time is taken for construction activities	Overlap in construction activities thus reducing overall construction duration of 17 months to 9 months
2	Acceleration of installation activities	Modularization of certain mechanical and electrical sections of the structure which were pre-installed together instead of installing at site
Safety Risks		
3	Working at Heights	Extended handrails were installed along the work zone
4	Fall of construction tools/ equipment through the cutouts on the floor for passage of mechanical equipment	Fall arrestors and temporary overhead protection measures were installed along these openings. Some areas of cutouts were cordoned off.
5	Reduce openings on the floor	PERI's modular systems were installed to reduce the size of the openings
6	Tower cranes assembled, commissioned and operated in a constrained site	4D model viewed using virtual reality lens to provide a sense of the safety risks
7	Plant & People Interaction	Exclusion zones were set up to ensure plant/people delineation during critical lifts.
Interface risks		
8	Number of interfaces between different crews at the site	Tunnels were isolated from the vent facility to reduce the number of interfaces
9	Client at risk of managing interfaces between different subcontractors due to their poor comprehension	Visualization exercise helped the subcontractors to understand the interfaces and logic of activities

PROGRAM RISK MANAGEMENT

1. The contractor's schedule was a mature schedule that had been followed for over a year; however, when the schedule was checked using the 4D CAD model, previously undetected concerns were discovered by the project personnel representing the owner's team. They claimed that using the 4D CAD model revealed that the schedule did not show a feasible plan for the delivery of the vent facility and there were a number of risks that could potentially delay the planned project completion date. Hence, the owners team took the initiative to develop a detailed schedule for the delivery of the vent facility based on the insights from the 4D visualization. Multiple scenarios were then considered so as to enable concurrent works and thereby time savings. This exercise enabled an overlap in construction activities resulting in an overall reduction of construction duration from 17 months to 9 months. Thus, the 4D visualization helped in identifying previously unknown risks which then needed to be managed.
2. In addition to this, with the visualization exercise, other opportunities for accelerating the schedule became apparent as unintended benefits. There were opportunities to have an increased number of pre-cast elements in the structure with careful installation planning. This meant pre-installation of multiple mechanical & electrical equipment together as modules instead of installing individual items of equipment into completed areas of structure. The changes in the project because of the 4D visualization exercise allowed time savings in the project.

Thus, to accelerate the program the key was to allow for more concurrency in the construction at different levels of the vent facility structure. This meant that different crews would have to work simultaneously at different levels which presented itself as a safety risk and required pre-planning, assessment, and management of the identified risks. It would have been difficult to predict how much of the structural and mechanical electrical works in the vent facility could be completed concurrently in a safe manner without a visualization exercise.

SAFETY RISK MANAGEMENT

There is a need for improving safety management practices in construction projects (Belayutham & Ibrahim, 2019). In this case study, as the review of the program was done in conjunction with the visualization model it became clearer that careful coordination and additional safety awareness were necessary to rotate crews between the three shafts of the vent facility. The 4D CAD model helped the project team visualize the safety risks that would arise during the execution of the project, for which suitable risk management measures were adopted.

3. The fall of person from heights is one of the major safety concerns in construction projects (Wong et al., 2009). The vent facility was comparable to the size of a 25-story residential tower and had workers working at different levels. With time being a critical component, the schedule had to be crashed as explained earlier and there were civil, electrical and mechanical workers working at the same time on different levels. This was an unsafe environment and it was difficult to predict how much of the structural and mechanical electrical works in the vent facility the contractor would be able to complete concurrently. The visualization exercise helped to show the space constraints and feasibility of working simultaneously at multiple levels of the vent facility. The 4D CAD

models helped the project team visualize the safety hazards of working at height and inform the contractor to prepare themselves for parallel fast track work at various levels. Extended handrails were installed along the work zone, which provided additional safety along with a scaffold stair access supplied for safe work access.

4. Since the project was the construction of a vent facility, there were cutouts on the floors for the passage of mechanical equipment. The 4D model highlighted that even when civil workers were working on the top floors, these cutouts were required to be kept open for use by the mechanical workers. This constituted a safety risk as the fall of construction tools/equipment from the upper level to the lower level can cause serious injury. Separation of activities was not an option because the mechanical and electrical workers were required to work along with civil workers due to time constraints. For mitigating this risk, fall arrestors and temporary overhead protection measures were installed along these openings. Adding to this, some areas of the cutouts were cordoned off to improve the safety of the site.
5. There were multiple cutouts on the floors and another strategy adopted was to reduce the diameter of these cutouts as much as possible. The project team identified the use of PERI's modular systems as an effective way to reduce the size of these openings. PERI's modular system has fully captive decks as well as penetration covers to reduce opening on decks.
6. The project was in a very congested site as it was in one of the prime locations of the city with considerable vehicular movement nearby. The lifting operations in the site were carried out using three tower cranes. These cranes had to be assembled, commissioned and operated in this small and complex site constituting another safety risk. The crane operators were not able to understand the construction complexity from the drawings which were meant for civil engineers who have the required technical knowledge to comprehend them. The 4D model created helped the tower crane operators to visually and virtually comprehend the complexities of working in such a constrained environment. The 4D visualization model was available to be viewed using virtual reality lens to provide a sense of safety risks while the mechanical & electrical equipment was being installed at different levels of the vent facility. Sacks, Perlman and Barak (2013) highlight that adding virtual reality to visualization can improve safety practices within the construction industry. There were also luffing cranes fitted with cameras and anti-collision systems. Even though the 4D models were not used as a formal training module for the tower crane operators as used in Goedert & Meadati (2008), it worked out well as a safety induction for the crane operators.
7. The construction site involved multiple workers belonging to civil, electrical and mechanical crews working concurrently. The 4D visualization exercise showed that there would be a potential 'plant-people interaction' safety risk during the erection of equipment. To mitigate these risk exclusion zones were set up to restrict the movement of people at the erection site during critical lifts at the site. These zones were accessible only to a limited number of people who are authorized to work in the particular activity as people from other disciplines were excluded.

INTERFACE RISK MANAGEMENT

Interface risks occur due to management issues between different stakeholders during concurrent works. Shokri et al. (2016) define interface management as the appropriate management of communications, relationships, and deliverables among stakeholders. Megaprojects are technically complex and at many times involve multiple stakeholders working concurrently at the construction site making interface management critical for successful project delivery.

8. In the case of the vent facility, the civil structural working crews, mechanical electrical crews, equipment installation and commissioning crews and tunneling crews were all working concurrently. Through the 4D visualization exercise it became clear that the working together of these different crews would result in unnecessary interactions and a potential interface risk. To reduce the interfaces between the civil structural crews and the tunneling crews, the vent tunnels were isolated from the vent facility during the construction of the vent building.
9. The interface of the vent building with the vent tunnels is visible in Figure 3 below. The concurrent working at different levels of the structure with continuous interfaces between mechanical & electrical crews and civil & structural crews need to be managed closely. Most of these crews belong to different organizations (subcontractors) and have their own scope. The client is always at the risk of managing the interfaces between these subcontractors as they do not comprehend the importance of handovers from one subcontractor to another. These interfaces became more visible after looking at the complexity of the vent facility structure and the logic of activities through the visualization exercise.

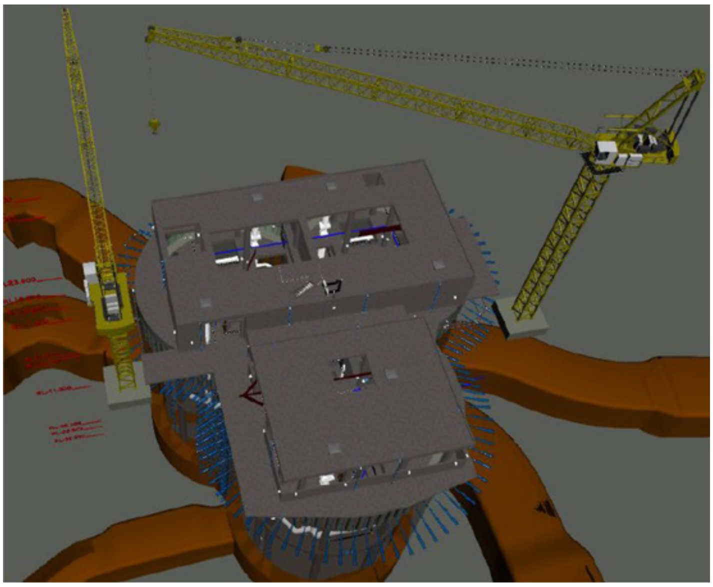

Figure 3 Vent tunnels interface with the vent building

Convincing non-technical stakeholders

The 4D model was used to demonstrate to the non-technical stakeholders such as the top management and other commercial stakeholders that the construction of the vent was a complex activity. Many of the mitigation measures for the safety risks explained in the section above required the approval of these non-technical stakeholders of the project. The 4D CAD models helped in highlighting the safety risks, however, any changes in design to mitigate the risks will have an impact on time and money. These changes would require the approval of the non-technical CEO, board members, and commercial partners, for whom the 4D CAD models helped in visualizing the complexities at the site and comprehending why these changes were necessary. Thus, the project team was able to easily convince the non-technical stakeholders for changes in designs with the help of the 4D models created.

Since the project was critical and politically sensitive, the CEO and the board needed to appreciate any forecast, and this needed to be communicated to the CEO and other stakeholders in a way that was easily interpreted, and technical complexities were well appreciated. In several cases, the contractor's schedule and logic required investigation as the contractor hadn't reported a delay in the schedule. The client's project team did not think that the schedule created was a realistic forecast as an internal assessment showed a delay to the project completion date. Thus, the client wanted to assess the risks to the project schedule, project timeline and logic. Visual 4D modeling was best suited to explain the complexity of the scope of work to the non-technical stakeholders. Such visual exercise helped them appreciate the complexity of the project and the risks inherent with the sequencing of the construction program.

In this case study, the initial motivation for developing the 4D schedule was to convince the board of any changes to the planned milestones. The need to convince non-technical stakeholders as initiators of BIM/visualization adoption in Australia along with project cost savings and improvements in data accuracy has also been reported by Hong et al. (2019). The main design and construction (D&C) contractor were driven to specially build a complete detailed program for the most complex part of the job while the independent model and the findings were shared with the D&C contractor. The contractor used the model to comprehend, confirm, communicate, coordinate and troubleshoot. The tool helped find logic enhancements and challenged the team to think alternate ways of construction while there was still time to adjust. It verified constructability, checked workflow, and acceleration.

Discussion

The use of visualization for understanding the vent facility in a megaproject helped us understand how the communication of risk information through 4D visualization helps in risk management in megaprojects. The findings are discussed through the knowing-doing gap theoretical perspective originally proposed in the organization science literature (Pfeffer & Sutton, 1999).

This research uses 4D visualization as a strategy that helps to address the issue of optimism bias found in the megaprojects that continued during the project. With optimism bias, the project proponents systematically underestimate the costs and overestimate the benefits of the project (Flyvbjerg, 2008). A psychological explanation of optimism bias categorizes it as a cognitive predisposition found with most people to judge future events in a more positive light or with optimism than is warranted by experience (Flyvbjerg, 2008). The solution to optimism bias is anchoring project decisions to a reference of actual performance available in reference class forecasting research (Flyvbjerg, 2006b). This research adds another solution to optimism bias in the form of 4D visualization as it helps the project team visualize the construction activities of the megaproject, providing a more realistic picture, thereby increasing the ability to forecast and mitigate the optimism bias risk among construction activities before they arise. This visualization can be categorized as visual control wherein effective project management can be enhanced by a visualization exercise to provide information on the work performed along with its potential problems (Majava, Haapasalo and Aaltonen, 2019).

The risks identified and categorized from the case are safety risks, program risks, and interface risks. The safety risk management helped the project team to forecast safety issues and enable the construction of the project as an accident-free project in a safe environment. A safety accident in such a project as sensitive as a megaproject would cause cost overrun, time overrun and enormous public relations issues for a megaproject that is already under intense public scrutiny. The program risk management helped the project team to visualize schedule discrepancies and enabled the use of efficient technologies such as the use of efficient formwork systems, precast elements, and efficient construction methodologies. The project team was able to ask the contractor to resubmit their schedule as it proved infeasible for construction when checked through the visualization model. This helped to address 'hold up' issues that could arise due to information asymmetry between the client (principal) and contractor (agent) issues impacting the cost of the project (Forsythe, Sankaran and Biesenthal, 2015). Through these measures, the project team could reduce the overall construction duration and thereby the cost. The interface risk management helped manage the interfaces between concurrent discipline works by developing safe construction method statements to manage work at the interfaces. Managing the interface will help to speed up construction through fast-tracking and also reduce costs if managed well.

The 4D model was also instrumental in convincing the non-technical stakeholders, such as the senior management and the project board members. It helped them visualize the construction sequence and understand the planned completion date before construction or understand the reason for the delay in the delayed areas. The visualization helped them appreciate the complexity of a megaproject compared to a conventional project as they are unable to make sense of technical drawings and construction schedules. The literature records the use of visualization, 4D in this research, for persuading stakeholders (Ninan et al., 2020). Persuading involves use of visualization for discussing and arriving at a mutual solution. The findings of Mahalingam, Kashyap and Mahajan (2010) discuss how a 4D CAD model was used by the contractor to convince the client. This research extends the existing literature by recording the practices of using visualization to convince non-technical senior management enabling them to take decisions.

Conclusion

While majority of research in megaprojects are oriented towards 'knowing' the problems and 'knowing' the solutions, there is a dearth in literature aimed at explaining strategies adopted in 'doing' or implementing that knowledge. This research sought to explore the role of 4D visualization for addressing the knowing-doing gap prevalent in these projects. The findings from the case study showed that 4D visualization, which includes the use of 3D CAD and schedule, helped the project team to understand the construction processes and the construction challenges using a communication medium that made sense to them. The article discusses how visualization helped mitigate various risks such as safety risk, program risk, and interface risk.

This research makes contributions to theory, practice, and research methodology. First, it helps us understand the role of visualization in bridging the knowing-doing gap in the construction industry in the context of a megaproject. Existing literature records how the challenges in megaprojects can be addressed through communication (knowing), however, visualization helps stakeholders in megaprojects communicate and address (doing) these challenges thereby bridging the gap between knowing and doing. Second, this research extends the existing literature on using ICT for visualization for persuading stakeholders (Ninan et al., 2020) by recording how 4D CAD is used for convincing non-technical stakeholders who hold senior management positions in the project organization. The project team was able to facilitate better discussions with non-technical senior management enabling them to understand, identify, and take better decisions to handle construction challenges. Since there were multiple benefits of using 4D visualization for risk management, we suggest all megaprojects adopt it contractually. Third, the case empirically describes how a megaproject that used traditional 2D drawings was able to successfully convert the 2D model into a 4D model by incorporating the scheduling data. Finally, we highlight how an autoethnographic study can give significant insights into the inner workings of a megaproject, in particular the confidential decision-making processes among top management.

The use of single autoethnography also poses a limitation on the triangulation and generalizability of the findings. However, the goal of autoethnography in this research was to uncover findings which were earlier inaccessible and therefore act as a stimulus for profound understanding (McIlveen, 2008). Livesey and Runesen (2018) argue that despite criticisms about autoethnography it 'can be applied analytically and rigorously so that it can be used for theory testing and theory building. In doing so, it opens up an untapped source of data to researchers – their own living experience.'. Autoethnography has been reported in construction management research to as a way of getting a better understanding of real problems faced at site in human interactions (Nugapitiya, 2007). Future research can explore the role of visualization for bridging the knowing-doing gap in other contexts. Another limitation of this study is the use of make-fix visualization model enabled by converting the 2D drawings available at the site into 3D drawings and 4D models. Multiple projects worldwide use BIM for visualization while also providing data accuracy and cost savings. Future research can explore the use of 4D BIM drawings for visualization and decision-making as it is a more advanced form with information on all the building elements. It is also worth noting that the visualization exercise can have helped convince non-technical stakeholders such as the project community and other external stakeholders. Future research can explore the role of visualization for managing external stakeholders.

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